On the solar poloidal magnetic field as one of the main factors for maximum GCR intensity for the last five sunspot minima

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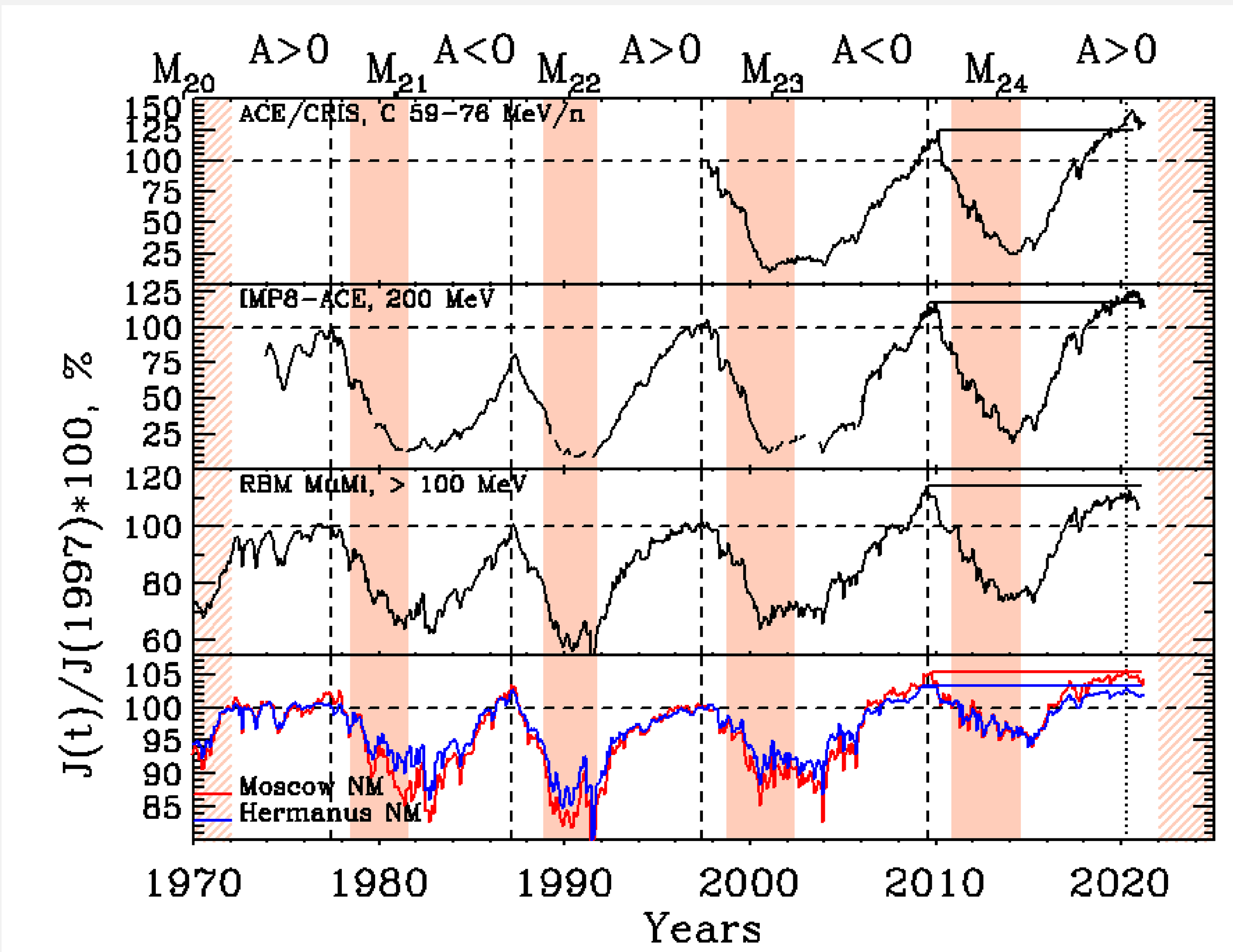
Main topics

- **Observations**: Minima of the solar cycle on the Sun, in the heliosphere, and in Galactic Cosmic Ray (GCR) intensity. Occurrence of maximum GCR intensity and dependence of corresponding main heliospheric factors (HFs) on poloidal SMF.
- **Calculations**: Modulated GCR proton spectra at the Earth using a 3D numerical model. Difference in calculated and observed proton spectra for 24/25 and 23/24 minima and dependence of the spectra on poloidal SMF.

Observations

Fig. 1 shows time profiles of GCR intensity for four different energies from 1970 to 2021 at the Earth, normalized to 1997 (the previous sunspot minimum when the magnetic field (HMF) polarity cycle was $A > 0$).

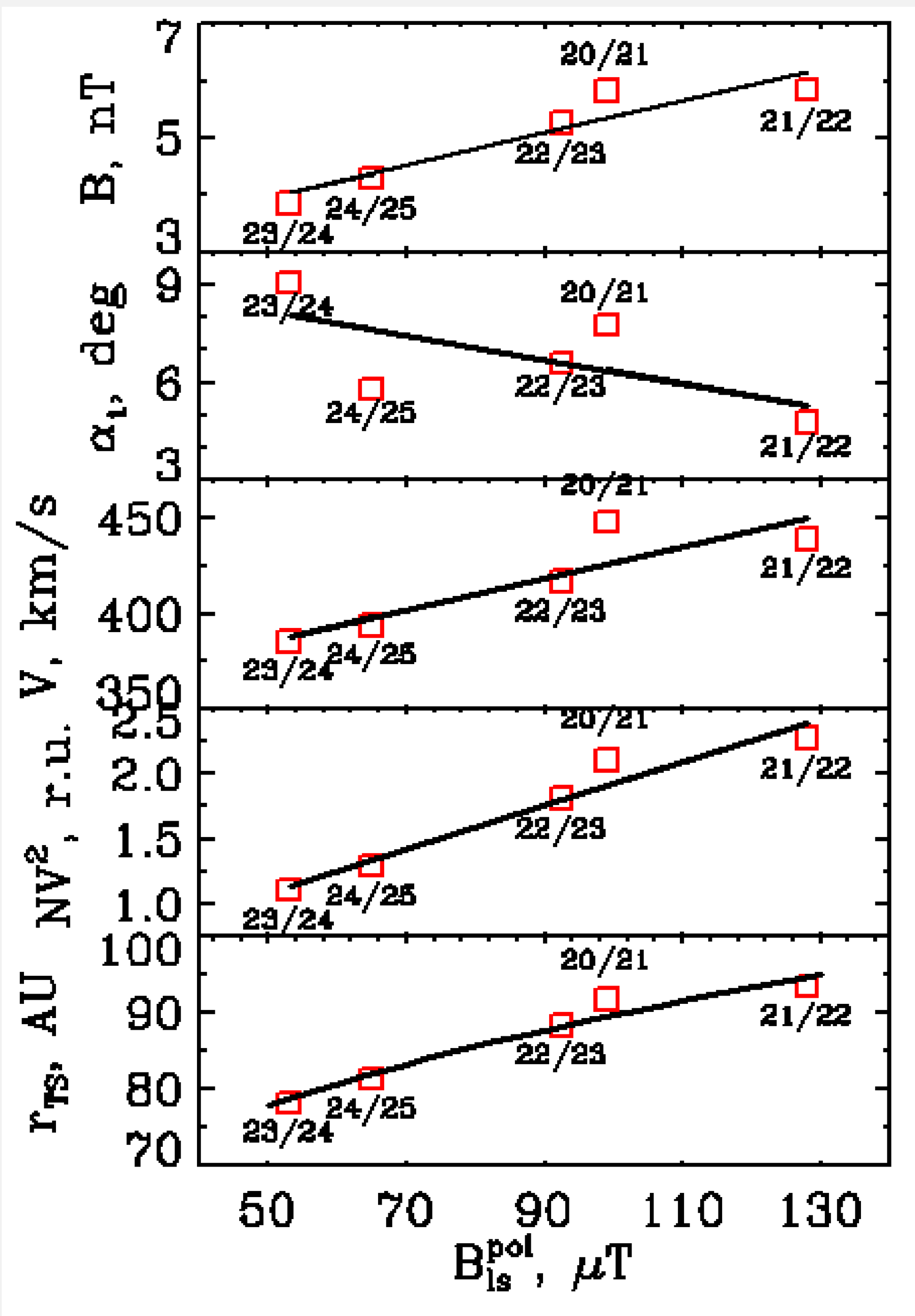


- Moments t_{Jmax} of maximum GCR intensity J_{max}.
- Difference between minima 24/25 and 23/24

Fig. 1

The GCR intensity already has reached its maximum value in minimum of solar cycle 24/25 with $J_{max}^{24/25} > J_{max}^{23/24}$, at least at lower energies.

Fig. 2 illustrates the dependence of HFs on poloidal SMF.



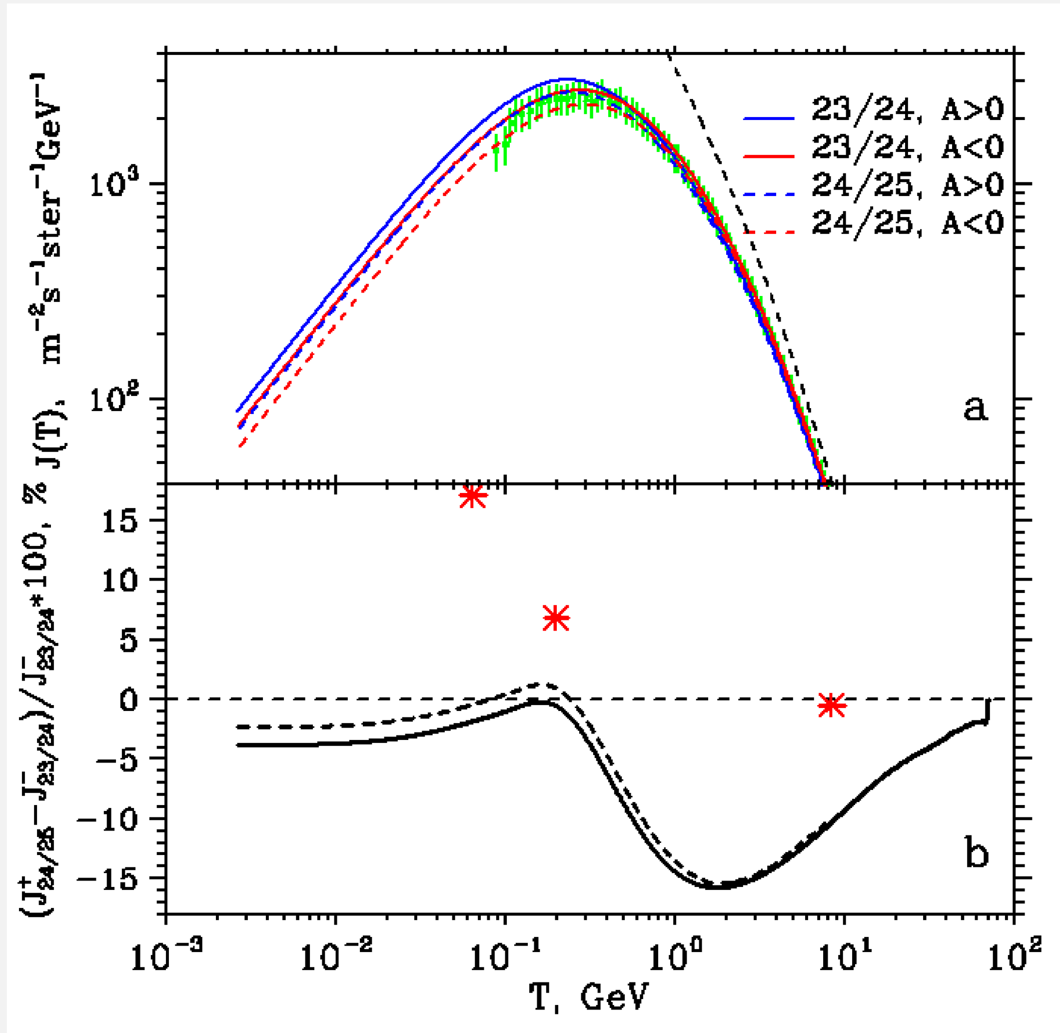
- Linear dependence on the poloidal SMF of all HFs
- Monotonous dependence of r_{TS}.
- In minimum 20/21 and for αt in minimum 24/25, some deviation from this trend.

Fig. 2

For heliospheric processes during sunspot minima magnitude of high latitude magnetic field is of leading important.

Calculations: Numerical modeling

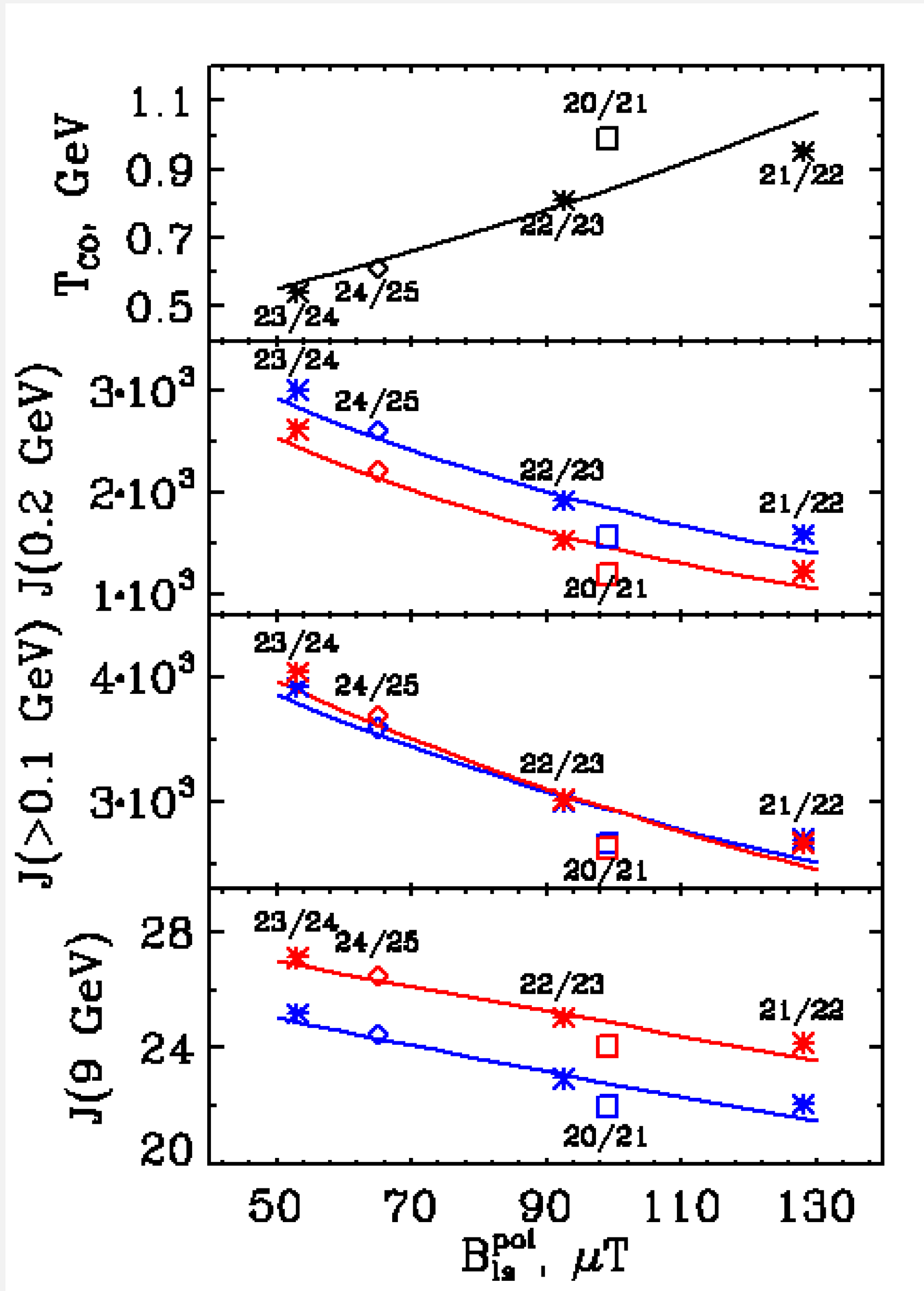
Fig. 3 shows the calculated GCR proton spectra near the Earth for two last minima with the corresponding HFs shown in Fig. 2 and set of descriptive coefficients described by Aslam et al. ApJ, 2019.



- In panel (a): PAMELA 23/24 (2009) protons with $S_{descr}^{23/24}$ from Aslam et al. 2019.
- For the same $S_{descr}^{23/24}$: $J_{max}^{24/25}(A>0) \approx J_{max}^{23/24}$ $(A<0)$
- In panel (b) the relative difference between $J_{max}^{24/25}(A>0)$ and $J_{max}^{23/24}$ $(A<0)$ with stars for observations

Fig. 3

Fig. 4 shows dependence on poloidal SMF of the spectral characteristics for both HMF polarities in trend and for real HFs in 5 sunspot minima.



- In trend (linear dependence of HFs on poloidal SMF):
  - T_{CO} grows.
  - *All J* decreases.
- For real HF for each minimum:
  - T_{CO} as in trend.
  - All J as in trend.
  - Deviations are greater than for dependence on B.

Fig. 4

Conclusions

- **The role of the poloidal solar magnetic field during sunspot minima both in the heliospheric characteristics and in GCR intensity is significant.**
- **For minimum of 24/25 (April 2020; $A > 0$): $J_{max}^{24/25} \geq J_{max}^{23/24}$ at least at low energies. The AMS-2 data for 2020 is important.**
- **Model describes the PAMELA spectra very well. The role of additional observable factors (local SW velocity, position of termination shock) is small.**

Acknowledgements

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